Implications of Fluid Dynamics Inside Arctic Sea Ice Sheets for Thermohaline Circulation and Biological Activity

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1. Summary

Background:
- Growing sea ice is a source of dense brine
- Arrangement of brine inclusions during growth may be crucial for meltwater drainage in summer
- Permeability and porosity at the ice-water interface constrain nutrient fluxes

 Aim:
 Characterize the modeled structure of growing sea ice, then extend investigation to melt season. Here: How can the sea ice salinity (and salt flux during ice growth) be parameterized? How big is the nutrient flux into the ice during growth? How does the continuum fluid dynamics model cope with coarse and fine grid sizes?

Method:
- Treat sea ice as porous medium, porosity $f$ (continuum approach)
- 2-dimensional finite volume fluid dynamics simulations
  - impose oceanic heat flux $F_o$
  - impose heat exchange with atmosphere
  - find empirical relationship for stable sea ice salinity $S$
  - determine the mass flux from ocean to sea ice

2. Overview

Desalination occurs:
- over a relatively short period of time ($\Delta t$) after initial freezing
- close to the ice-ocean interface

Energy balance at the ice-ocean interface:

$$F_o = \frac{\partial T}{\partial x} = 0$$

Fluid dynamics simulations use a permeability–porosity relationship similar to Petrich et al. (2006) (red) or Eicken et al. (2004) (black).

3. Computational domain

- Oceanic heat flux
  - imposed 0.1 to 0.2 m below the sea ice–ocean interface
- Sea ice–atmosphere interface: constant $T_0$
- Domain is periodic horizontally

4. Salinity profile

- Ice–air interface temperature $-20^\circ$C
- Oceanic heat flux $F_o = 0$ W m$^{-2}$

5. Modeled stable salinity

Simulated ratio between stable salinity $S$ and seawater salinity $S_0$ as a function of growth rate $v$.

$$\frac{S}{S_0} = 0.14 \left( \frac{2}{3.35 \times 10^{-8} \text{ m s}^{-1}} \right)^{0.33}$$

The stable salinity of growing sea ice can be predicted based on the growth velocity, independent of oceanic heat flux.

6. Stable salinity data

Measured ratio between stable salinity $S$ and seawater salinity $S_0$ as a function of growth rate $v$ of Granrooy et al. (in press) (circles) and Nakano and Sathu (1981) (crosses). The broken line follows Equation (1).

$$\frac{S}{S_0} = 0.18 \left( \frac{2}{3.35 \times 10^{-8} \text{ m s}^{-1}} \right)^{0.30}$$

7. Ocean–sea ice mass flux

Preliminary estimate of an upper limit for the availability of nutrients: each volume of sea ice $V_i$ is penetrated by a volume of ocean water $V_F$ during growth.

$$\frac{V}{V_i}$$ from a typical permeability parameterization (after Eicken et al. (2004), cf. Box 2).

Various grid sizes and surface temperatures $F_o = 0$ W m$^{-2}$

8. Sea ice–ocean transition

Simulation at high growth rate ($\sim 30^\circ$C surface temperature): permeability after Petrich et al. (2006), 0.5 mm resolution. The interface is rough at the mm-scale, systems of brine channels and feeders appear.

9. Conclusion

- Continuum fluid dynamics simulations are able to produce realistic average sea ice salinity profiles.
- The model suggests that the average salinity profile (and hence salt flux during growth) can be predicted based on the ice growth rate.
- The cumulative, maximum nutrient supply to ice algal communities can be evaluated, shedding light on patchiness and spatial differences in biomass.
- The model can be extended to the melt season to investigate brine percolation, and evolution of porosity and nutrient fluxes at the ice–ocean transition.

10. Acknowledgements and References

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References


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